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Development and learning: a TASC-based perspective of the acquisition of perceptual-motor behaviors

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Abstract

The concepts of development and learning are discussed in terms of different theoretical orientations to the study of motor behavior. It is argued that although these concepts are commonly used to discuss various aspects of change across the life span, there is little agreement regarding the definition of these terms and even whether these are useful concepts for researchers studying change over time. A theoretical approach, the TASC-based approach is presented as an alternative account for examining change over time. The TASC label stands for a focus on particular *tasks*, *adaptation* and *selection* of behaviors as a function of *constraints*. This account is grounded in evolutionary theory and assumes that variability, selection, and adaptation are central to change over time within individuals. Emphasis is placed on the tasks individuals attempt to solve in achieving particular goals given the constraints of the local environment and the organism. An alternative manner to conceptualize the concepts of development and learning are presented within the TASC-based approach.

Keywords: Development; Learning

1. Department and learning: a TASC-based perspective

Researchers have used the terms "development" and "learning" in a variety of ways with the importance of viewing these concepts as separate and distinct varying as a function of

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the dominant theories of the time (see Pick, 2003). These two terms are used extensively by researchers in discussion of research findings, seemingly based on the underlying assumptions that: (a) there is wide-spread agreement on what these terms mean, (b) that these terms capture different underlying processes, and (c) that changes over time are more likely the result of one or the other of these two "distinct" processes. We suggest, however, that these assumptions are not valid and that we need to reconsider how the terms "development" and "learning" are conceptualized.

To some extent problems with defining "learning" and "development" may be attributed to the fact that no single theory dominates the study of human behavior and how behavior changes over the life span. There is no grand unifying theory (GUT) that serves to guide research and practice in this discipline. One outcome of this lack of unity is that different researchers and theorists use and define these terms within the contexts of their own particular theoretical orientation, with little agreement in how these terms should be defined across theoretical perspectives. Not surprisingly, one outcome of these disparate views is that researchers from different theoretical orientations provide greater or lesser emphasis to concepts of development and learning within their explanatory accounts. We begin by briefly outlining some distinctions that have been drawn regarding the concepts of development and learning, acknowledging that an exhaustive account of these distinctions is well beyond the scope of this paper. We use these distinctions to highlight differences in theoretical accounts and suggest that perhaps the only way to clarify these two concepts is by the construction of a more unified account of how human behavior changes over time and we make some preliminary suggestions about what that account might include.

In order to clarify the theoretical underpinnings of the various definitions of development and learning, we take two quite different theoretical views to serve as an initial backdrop for our discussion. Specifically, we contrast maturational accounts and an information processing perspective of changes in human behavior over time. We choose these two perspectives because their differences in underlying assumptions and foci enables us to examine the concepts of development and learning from two relatively extreme positions. Other theoretical accounts provide somewhat of a middle ground between these positions.

Advocates of the maturational perspective often suggest that their focus is on "development." From this perspective, development is typically defined as a change brought about by maturation and endogenous influences. These "developmental" changes are often characterized as involving a broad level of change that permeates the system (domain general), occurs over a long time scale (many years), and results in lasting change in the organism. In contrast, advocates of the information processing perspective often suggest that they focus on "learning," defined as a change in behavior brought about by experience and exogenous influences. These changes are often thought as relatively narrow in scope, not thought to generalize except to similar behaviors or situations (domain specific), thought to generally occur over a short time scale (often a single session), and are thought to sometimes, but not always result in a relatively permanent change in the organism.

Given these distinctions, it is not at all that surprising that researchers focusing on "development" often study infants and very young children assuming that this is the best time to capture change in behavior unsullied by exogenous influences, and researchers focusing on "learning" often study older children and adults assuming that "developmental" processes will no longer complicate the "learning" process. Clear example of this split can be seen with respect to the acquisition of perceptual-motor skills. Motor "developmentalists" traditionally have been aligned with maturational approaches. Indeed, the entire field of "motor development" has as its organizational theme the understanding of "development" as opposed to "learning." Researchers and theorists from this traditional perspective (e.g., Gesell, 1929, 1933; Halverson, 1931; McGraw, 1943; see for an overview: Pick, 2003) viewed children and adults as qualitatively different from one another with much of the difference being driven by the maturation of distinct structures in the central nervous system. From this perspective, development and maturation are often treated as synonymous, except that development is typically reserved for those behavioral changes that occur toward the beginning of the life span, especially those occurring in infancy and early childhood, and maturation is applied more broadly across the life span.

Many of the early motor developmentalists focused on the emergence of particular behaviors, such as sitting, grasping, walking and running. These fundamental movement patterns have been labeled as "phylogenetic" behaviors (McGraw, 1935/1975; Newell, 1986). Phylogenetic behaviors and changes in these behaviors over time were thought to be relatively uniform across individuals in terms of timing and order. Change was described as qualitative in nature and driven by underlying maturational processes. In contrast, "ontogenetic" behaviors were defined as behaviors that were not viewed as fundamental for survival and were more idiosyncratic to individuals. It is these ontogenetic behaviors that were left to the researchers interested in "learning."

For the most part, researchers investigating motor "learning" have been interested in the processes that lead to changes in the behavior of older children and adults, when the human organism has mostly matured. From the motor "learning" view, the actual behavior under scrutiny has traditionally been thought of as less important than understanding the underlying process of behavioral change. In this manner no particular behavior is viewed as more central than another based on the assumption that similar processes govern the acquisition across different behaviors and tasks. Researchers from this perspective also tend to view children and adults on a continuum, with children viewed as less efficient learners than adults.

None of the aforementioned distinctions are all that satisfying. This dissatisfaction stems from a general difficulty in the application of these terms to real examples. Do children "learn" to crawl or walk? Or does the ability to locomote "develop"? Do children "learn" to grasp writing implements? Or do children's grip configurations "develop"? Do throwing and catching "develop"? Or are throwing and catching skills "learned" (Roberton, 1984)? These examples highlight the "fuzziness" of these concepts and the theoretical baggage that come with their use. One might in fact question whether there is any advantage in using the terms "development" and "learning" at all. Indeed, it may very well turn out that these terms fail to capture any useful distinction at all. If this is true, then it is perhaps time to "retire" these terms and potentially create some new term or terms for capturing change over the life span. This may be the best approach, however, it might be fruitful to examine these terms once more, but with the goal of determining whether a more clear distinction can be made between them.

Our goal in the present paper is not to provide a comprehensive review of the diverse perspectives on learning and development (see Pick, 2003 for a historical perspective on these terms), but mainly to provide some thoughts on how we might resolve some of the definitional ambiguity of these two terms and whether it is actually meaningful and useful to treat these terms as distinct and mapping onto to distinct processes. With this latter goal in mind, we suggest some potential ways in which it might be useful to investigate whether the terms "learning" and "development" map onto different processes. We begin by addressing some issues with the traditional motor milestone approach and then provide a brief discussion of dynamic systems approaches prior to describing our approach.

1.1. Perceptual-motor milestones

Much of research examining the acquisition of motor behaviors in infancy and childhood has focused on the "development" of action systems. These action systems include such complex behaviors as walking (Thelen & Cooke, 1987; Thelen & Ulrich, 1991), reaching (Savelsbergh, Von Hofsten, & Jonsson, 1997; Thelen & Smith, 1994), and grasping (Newell, Scully, Tennebaum, & Hardiman, 1989; Van Hof, Van der Kamp, & Savelsbergh, 2002). The focus in motor development research has traditionally been on trying to understand the "process of development," with emphasis on careful description of the emergence of a particular behavior.[1] These careful descriptions were often quite elaborate consisting of many "developmental" stages with particular behaviors viewed as "maturing" at particular ages in young children (Gesell, 1929; McGraw, 1943). For the most part, the behaviors of focus were classified as "phylogenetic" and fundamental to the survival of the species. These age-based descriptions lead to the creation of "motor milestones" that can be found in any developmental textbook (see Thelen & Adolph, 1992, for a discussion of Gesell's role in the creation of these milestones). Von Hofsten (1993) has suggested that "age norms are important for helping us to form expectations about age-specific performance" (p. 110), but the focus on age norms can be problematic.

The focus on age-specific changes implies that the emergence of the motor milestones is driven by maturational changes common to all members of the species. Description of motor milestones as relatively stable and predictable has served to reinforce this assumption. Indeed, the whole idea that performance might be age specific assumes a level of consistency across children; one that it is hard to imagine could be accounted for by anything other than a similar maturational process driving change in all children. We argue that this traditional perspective has treated "development" as equivalent to maturation, which makes the reification of age-based norms seem reasonable. In our view they are not. Rather one of the central arguments of our approach is that we need to move away from age-based norms and their implicit maturational assumptions.

Von Hofsten (1993) has suggested a number of additional limitations in using age norms. First, norms are highly dependent on the population that provides the norming sample. Even a cursory examination of the motor development literature and of the "norming" samples used in many standardized tests suggest that these norms are most applicable to infants and children of predominantly white, middle-class families in the United States. As Thelen and Adolph (1992) discuss, Gesell used highly restrictive sampling in the creation of his developmental norms and more alarmingly these norms still serve as the basis for a number of standard assessment tools. Restrictive norming samples severely limit the usefulness of an assessment tool for children who vary from the norm because these are by definition likely to be outside the "norm" and thus look "delayed" in some aspect of behavior.

A second limitation cited by Von Hofsten (1993) stems from the fact that norms are derived by pooling data for groups of individuals. This process leads to an overall smoothing of the data and serves to hide any fluctuations or discontinuities that exist, making the acquisition of a behavior look incremental and continuous. A related limitation of age norms is that they serve to "hide the great natural variation in motor development between individuals" (Von Hofsten, 1993, p. 110). This notion of inherent variability is a central theme of our approach.

Reliance on age norms can also obscure the underlying cause of variation (Von Hofsten, 1993). That is, one cannot determine whether variation from the norm is due to normal variation or to some sort of pathology. We suggest that the use of age norms in clinical practice leads to the assumption that variation is deviant and that the deviation stems from an underlying pathology. For example, children who score below the 5th centile in tests of motor behavior, such as the Movement Assessment Battery for Children (Movement ABC; Henderson & Sugden, 1992), are classified as having Developmental Coordination Disorder (DCD, also referred to as Developmental Dyspraxia or Clumisiness). Although this "disorder" is recognized as such by clinicians, and can be found in the Diagnostic and Statistical Manual (DSM-I; American Psychiatric Association, 1994), little evidence exists to suggest that this "disorder" reflects any underlying pathology. Indeed, the standard definition of this disorder is "a coordination disorder resulting from developmental delays in motor skills, *not* due to another medical or neurological condition." We suggest that if motor behavior is normally distributed, scores in the bottom 5% may reflect normal variation rather than some underlying pathology.[2]

The problem of determining what is and what is not pathological has important implications for therapeutic interventions. Specifically, if deviations from motor milestones are viewed as pathological, stemming from some "maturational" problem rather than caused by "normal" variation around a particular level, different types of interventions may be proposed. Specifically, genetic techniques, medicinal approaches, and interventions that attempt to "correct" global functioning may be favored to treat "maturational" problems. If, however, deviation is thought of as a "typical" rather than "pathological," practice and experience targeted to "correct" specific problems might be offered to attempt to bring performance up to the norm. Not surprisingly most therapeutic approaches in the field of motor development appear to be based on underlying maturational models and the overall success at improving the quality of movement in young children has been quite mixed. In contrast, task-specific interventions focusing on helping children accomplish specific goals appear to have some promise (Parker & Larkin, 2003).

An additional problem with a focus on age-based norms is that this focus often leads to the study of behavior in relative isolation. That is, researchers who have studied the acquisition of locomotor skills, the acquisition of grasping, the acquisition of throwing, etc. have traditionally not attempted to understand the contextual factors that influence the emergence of these behaviors. Specifically, researchers have not been concerned with how these actions fit with the *specific goal that the child is attempting to achieve*. Foo and Kelso (2001) have suggested that the individual's goal serves to provide meaning to the sources of information present in the environment. This goal also serves to determine in a dynamic way how different sources of information are used and the relative importance of the information present. By divorcing the process from the goal, the action systems have become disembodied from the living, thinking, goal-oriented child.

Although the major milestones of the various action systems (reaching, walking, etc.) may show a relatively uniform sequence across children in terms of their emergence and be relatively similar across children in their behavioral instantiation, we suggest that it is perhaps time to call into question the very idea of motor milestones. The primary reason for questioning the existence of motor milestones lies in the fact that the data that serve as the basis for these milestones was collected within the context of maturational theories that assumed that "development" was stable and uniform across children. It is clear that theoretical orientations influence the research questions asked, the methodologies used to collect data, and the manner in which the data is interpreted (Overton, 1998). It is somewhat surprising to us that given the widespread criticism of maturational accounts that there has been little or no questioning of the validity of motor milestones. Many researchers have distanced themselves from maturational accounts by suggesting the milestones are "age-related" rather than "age-based" (Clark & Metcalfe, 2002). The problem with this approach is that the "stability" of motor milestones is relatively well-entrenched in the larger culture—and a more radical departure from these norms may be necessary for real changes to occur in the way change over time is conceptualized (by both researchers and non-researchers).

Additionally, if we question the assumption of the dominant role of maturation in leading to changes over the life span, then it may be necessary to question both the data and the conclusions drawn from the data that were collected under that assumption. That is, we suggest that it may be time to re-examine the stability of developmental sequences along with the consistency of motor milestones.

We suggest that emergence of various behaviors across the life span is not fixed by age, but arises from an interaction of constraints as a child tries to solve a particular problem. That is, the emergence of various motor behaviors needs to be examined in the context of the task that the child is trying to solve. The emergence of certain motor behaviors, such as the onset of walking, are likely to be relatively uniform (in terms of the sequence of their emergence and overall form) because they have *evolved* as optimal solutions to particular problems that threaten a child's survival at particular periods of his or her life. They are also likely to show relative uniformity because they emerge due to a highly similar configuration of interacting constraints when different children are attempting to achieve the same or similar overall goals. It is the uniformity of constraints, not age that lead to similarity in overt behaviors across children.

With respect to other motor behaviors, such as the emergence of belly crawling or a dynamic tripod grasp with respect to writing, we see these behaviors as less necessary for survival and less likely to be determined by a specific set of interacting constraints that are similar across children. Our prediction is that these behaviors will not likely show the same degree of uniformity in appearance (not all children will exhibit these specific behaviors) or form (the specific manner in which these behaviors are achieved may vary greatly from child to child) that is found for those behaviors that are fundamental for survival. In these cases no single optimal solution may emerge, but a number of different behavioral solutions may have a relatively high probability of emerging.

1.2. Dynamic systems approaches

Periodically, there is renewed desire for a unified theory of development. Lewis (2000) has argued that a "vital goal for the next generation of developmental theorizing" is to formulate a "converging explanatory framework" (p. 36). In his view, this has already been accomplished by dynamic systems approaches. He suggests that the concept of self-organization, specifically, the concept that stable patterns (order) emerges from the spontaneous interaction of components in physical, chemical, and biological systems, provides the single explanation for any and all developmental change. Likewise, Horowitz (2000) has claimed that there is a growing consensus that human development is a complex, multi-causal process. This view is clearly supported by others taking a dynamic systems perspective (Smith & Thelen, 1993).

Thelen and Smith (1994) have suggested that the dichotomy of development and learning is not a meaningful one from a dynamic systems view because both of these processes occur all the time and it is impossible to tease apart when one of these processes occurs without the other. That is, the acquisition of any new form of behavior is a dynamic one involving the self-organization of many different components of the system. Some of these components may change as a function of "developmental" processes, while others may change as a function of "learning." Because no resultant behavior is "hardwired," all behaviors are viewed as stemming from this complex self-organization process, and all behaviors might then be viewed as dependent upon both "learning" and "development." In many ways this perspective might lead one to conclude that the concepts of "learning" and "development" are no longer of much use.

Should we dispense with these terms? Do they provide any meaningful distinction regarding the acquisition of particular perceptual-motor behaviors? One way to evaluate this is to examine whether dynamic systems accounts and the concept of self-organization can provide a unifying theoretical account of development. To the extent that they do, it suggests that we really should consider dispensing with the concepts of "development" and "learning" and perhaps label all change as due to "self-organization."

In our view, research from this theoretical perspective has made substantial contributions to the field of motor development (Thelen & Ulrich, 1991) and language development (Van Geert, 1991, 1993) but has yet failed to make serious inroads into other aspects of developmental research and theorizing. Although one could argue that this stems from problems with researchers understanding the theory (Lewis, 2000), we suggest that the problem is deeper. Specifically we suggest that while dynamic systems approaches can be quite helpful for aiding our understanding of certain types of behavioral change, we suggest that the theory is unlikely to become (at least in its present manifestations) the GUT of development. We suggest that current dynamic systems accounts have two major limitations.

The first limitation concerns the problem that no particular behaviors appear to be privileged in dynamic systems accounts. Researchers from a dynamic systems perspective have examined a variety of rhythmic behaviors such as stepping (Thelen & Ulrich, 1991), infant bouncing (Goldfield, Kay, & Warren, 1993), and various combinations of limb movements (e.g., Amazeen, Amazeen, & Turvey, 1998; Kelso & Jeka, 1992). The emergence and overall organization of these behaviors is viewed quite similarly, with all being described in terms of self-organization of certain behavioral states. Likewise there is no privileged reason for preferring to study one or another of these behaviors because the same underlying principles of self-organization are thought to apply equally well for any and all behavior. We suggest that some behaviors are in fact privileged and should perhaps be viewed as emerging from a different set of constraints than others. In particular, we suggest that the course of human evolution has served to "privilege" some behaviors over others and that the behaviors that are privileged shift as a function of changing task, organismic, and environmental constraints. We will explain our perspective on this in greater detail in a later section.

The second limitation of dynamic systems accounts is they that they fail to address why a particular behavior emerges at a given point. In our view, this why question is central and must be addressed by any theoretical account of the acquisition of motor behaviors in infancy and beyond. Self-organization does describe a potential process underlying the emergence of a behavior but it does not provide an explanation for why a behavior might emerge. We suggest that one potential way of addressing the why question is to examine the emergence of behavior from an evolutionary perspective. Ethologists have often phrased this why question in terms of the function of particular behaviors, with specific attention given to how a behavior relates to survival value and the investigation of the elements in an immediate situation that impact on the expression of a particular behavior (e.g., Tinbergen, 1960). This functional assessment of behavior is lacking in current dynamic systems accounts.

In our view, the issues of behavioral function, survival value, and individual goals separate the human complex system from other complex systems such as weather systems. Indeed, if the function of a behavior is considered from an evolutionary perspective, seeming errors, such as the A-not-B error, can be viewed as perhaps functionally correct in some environmental contexts (Hailman, 2001). Specifically, Hailman argues that producing the A-not-B behavior is quite adaptive in terms of foraging for food. He provides the example of bird attempting to eat some ants. For example, an ant emerges from a hole (location A), and then disappears back into the hole. Another ant emerges and does the same thing. Soon after another ant emerges and hides behind a nearby leaf (location B). Where should the bird that has been observing this process look for its next meal? Although searching behind the leaf may provide a tasty morsel, searching at the hole is likely to be more fulfilling in the long run. By examining the how and why of the behavior in contexts where it might occur, the behavior is rendered more meaningful.

1.3. The TASC-based approach to changes in perceptual-motor behavior

In response to problems we perceive with past and present theoretical accounts of the changes occurring in perceptual-motor behaviors across the life span, we have been constructing the TASC-based approach. The TASC label stands for a focus on particular *tasks*, *adaptation* and *selection* of behaviors as a function of *constraints*. We suggest that the TASC-based account might provide a useful structure in which to consider possible differences between "development" and "learning." We present this approach, not as a GUT, but to suggest some essential building blocks necessary for any unified approach to examining changes in behavior over time.

1.4. The role of variability

Our approach is focused on functional tasks rather than on chronological age. In part, we propose this approach as a way of coping with the fact that change within an organism over the course of its life span is characterized more by variability than stability. Indeed, we suggest as Siegler (1994, 1996) and Thelen and Smith (1994) have, that variability is an essential characteristic of human behavior. Siegler (1994), for example, argues that variability plays a crucial role in driving changes in children's cognition. With respect to infancy, a growing number of researchers have begun to believe that variability in early infant movements is an essential aspect of normal motor development (Thelen, 1996; Touwen, 1990; Turvey & Fitzpatrick, 1993) and a fundamental aspect of all complex systems (Thelen & Smith, 1994). Indeed, research investigating a variety of biological systems, including investigations of human postural control (Newell, van Emmerik, Lee, & Sprague, 1993), and studies of human physiological systems (Goldberger, Rigney, & West, 1990), suggest that healthy biological systems are exhibit a greater level of variability (i.e., they are more chaotic) than diseased ones. In the realm of motor behavior, for example, Prechtl (1997) has found that infants who exhibit limited variability in their movements in the first few months of life are more likely to develop abnormalities in motor development, such as Cerebral Palsy.

The recognition that variability is an essential aspect of the human biological system requires a major shift in the focus of developmental studies. Traditionally, the only form of variability of interest to developmental researchers was variability due to age. But as Siegler (1996) has pointed out variability is also present within individuals performing the same task repeatedly and between individuals of the same age. In our view, we need to move away from a focus on age-based or even age-related milestones. Rather the focus should be on why and how children solve particular tasks that they are confronted with at different points in the life span. In order to answer these why and how questions we need to understand the function of behaviors in the context where they occur.

Some of the core ideas of the TASC-based approach, namely the importance of constraints, selection pressures, and variability, can be illustrated by changes over time of the mosquito populations in the London Underground. Byrne (1999) found that over time the population living in the underground became distinct from the population that lives above the ground. For instance, the above population bites birds and has a winter diapause, while the underground population bites mammals and has no winter diapause. These adaptations to the new Underground environment are a result of survival pressures. The evolution of the 'underground mosquito' came about due to selection of certain behaviors due to changes in the environmental constraints. Specifically, birds were unavailable as a source of food and temperatures in the Underground tend to be higher on average than those on the surface. These changes in environmental constraints (temperature and availability of food) led to adaptations of the 'above mosquito.' If the mosquito population had not exhibited some variation in basic behaviors (i.e., a taste for alternative food sources), the mosquito population underground would have died off. Instead, they adapted to the changes in environmental constraints and continue to flourish (much to the chagrin of Underground travelers!).

The point of this example is that any theoretical account of the emergence of some behavior (a "developmental" theory) must acknowledge that behavior emerges in response to a particular problem of adaptation (defined here as a "task"). Variation in the set of possible behaviors enables the organism (at the species and individual level) to select different behaviors to adapt to changing constraints. Variability provides the avenue for successful adaptation. An intrinsic goal of biological organisms is the solution of various tasks that they are confronted with over the course of their life span, in particular those tasks that threaten survival. We expect that a relatively small set of optimal solutions have emerged over the course of human evolution to solve problems that threaten survival within the typical environmental constraints found on Earth. We return to this issue of optimization in a latter section. As children grow and mature the particular tasks they are confronted with change as well.

Part of the goal of any explanation of the emergence of new human behaviors should be the articulation of specific tasks that must be solved over the course of an individual's life and an explanation of the importance of a particular task at a particular point in the life span. In our view, the central aspect of any "developmental" theory should be a focus on behaviors that have evolved as solutions to problems associated with functional tasks (those that must be solved in order for an individual to survive). This approach enables us to move beyond purely descriptive accounts to explain *why*, *how*, and even perhaps *when* a certain behavior emerges.

Our approach takes at its core, evolutionary theory, and particularly the concepts of adaptation, variation, and selection. Although other theories in developmental psychology have drawn from evolutionary theory, these tend to only apply evolutionary theory in a limited fashion while primarily borrowing metaphors from other disciplines (e.g., dynamic systems theory) or restrict the scope of behaviors that they address to a relatively small set of behaviors (e.g., attachment theory). We see our view, while sharing certain evolutionary assumptions, as distinct from traditional evolutionary biological explanations of behavior (Geary & Bjorklund, 2000). Specifically, the goals of evolutionary developmental psychology have been to "identify the social, psychological, cognitive, and neural phenotypes that are common to human beings, and to other species, and to identify the genetic and ecological mechanisms that shape the development of these phenotypes and ensure their adaptation to local conditions" (Geary & Bjorklund, 2000, p. 56).

We share with this theoretical perspective a focus on the function of behavior. For example, Byrne (1995) has suggested that an extended period of maturation is related to the greater and more sophisticated use of tools in some species and that tool use serves the function of facilitating later food gathering. We suggest that we should always be asking "what is the function of this behavior?" both in the current situation and over the course of evolution. Focusing on function leads us to prioritize certain behaviors over others, and to search for functional linkages between different behaviors, as we attempt to understand how change occurs over the life span. A focus on function also provides a potentially richer description of behaviors at particular points in the life span. For example, aspects of immature perceptual and cognitive abilities are often viewed as simply that. However, from an evolutionary perspective Turkewitz and Kenny (1982) have suggested that immaturity in the infant visual system might serve a protective function preventing over-stimulation. We suggest these early limitations of the infant visual system might also enable the infant to better focus his or her attention to particularly important aspects of the visual environment, such as the face of a caregiver, and in this manner gradually acquire visual information in manageable amounts from what would otherwise be overwhelming amount of visual information. In a

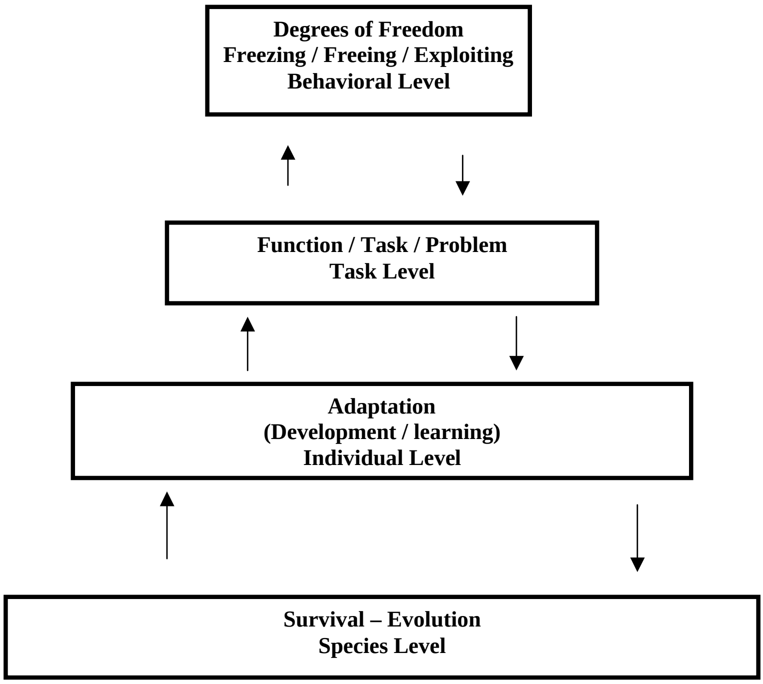

Fig. 1. The TASC model.

similar vein, Bjorklund (1997) has suggested that an immature cognitive system, with a limited auditory memory span may function to reduce the amount and complexity of language that young children process and in this manner enhance comprehension as children acquire language.

The TASC-based approach differs from evolutionary developmental psychology in a number of ways. We capture this difference in part in Fig. 1. In our view, researchers in evolutionary developmental psychology tend to focus at the species level shown at the bottom of the figure and strive to create explanations for behavior at this macro level of analysis. In contrast, we are primarily interested in the three levels depicted above the species level; the individual, the task, and behavioral levels. While the evolutionary level provides the overall structural framework for the processes that occur above it, we suggest that it is at the three higher levels where development and learning take place. To a large degree our differences lie in the level of analysis. We are more interested in the micro level, while evolutionary developmental psychologists are more interested in the macro level of analysis. Our emphasis on the top three levels of Fig. 1 also represents a lesser focus on genetic factors contributing to individual differences than researchers emphasizing the bottom level. In our view, the field of perceptual-motor development has traditionally placed too great an emphasis on genetic and maturational explanations and that these tend to lead to a focus on commonalties rather than variation. Genetic contributions and rates of maturation in our approach serve as organismic constraints that always interact with task and environmental constraints as well as other organismic constraints, including the goal of the individual in the ongoing task situation.

2. General principles of the TASC approach

2.1. Task focus

Because of the inherent variability both within and across developing organisms of the same species, we propose that a task-based, rather than age-based description of how behaviors are acquired over the life span will best enable us to examine the underlying processes that lead to change. Focusing on age-related changes over the course of an organism's life obscures variability that is inherent throughout the life span and implicitly leads to the inference that changes are driven primarily by maturational processes that are innately driven. An age focus also ignores the inherent dynamic between organism and environment and the inherent dynamic within the changing organism. Behavioral change does not emerge purely from an individual, but emerges from the interaction of the organism and environment as the organism struggles to adapt and solve particular problems.

What do we mean by "tasks"? We use the term "task" to refer to particular problems the child faces over the course of his or her life. Some of these tasks present fundamental problems to the child that he or she must solve in order to survive. Young infants face a number of fundamental problems that they must figure out how to solve. These include figuring out how to work one's body so as to acquire food, escape from danger, or explore the surroundings. Other tasks are less essential for survival but may be important for success (here defined as optimal performance) in a variety of different domains (e.g., family, school).

The tasks specified in this approach are not arbitrary, but defined by problems the developing organism is confronted with over its' life. We label particular tasks that are necessary for survival "Developmental Tasks." It is the solution to these tasks and the processes of adaptation to environmental pressures that lead to the selection of certain behaviors that serve as solutions to these tasks that a "developmental" theory should be built on. In this manner, certain behaviors have "priority" over others and it is these behaviors that "developmental" theories should strive to explain.

In the early parts of life, these "developmental tasks" may follow a fairly uniform chronology (though one that is only loosely coupled with age). In this sense, we do not wish to do away with any type of reference to age, we merely want to de-emphasize the importance of age in developmental accounts. Thus, our claim is that our focus should be on the problems (or tasks) that children confront over the course of their lives. Within this framework, examining variation in the age at which most children solve a particular problem or acquire a particular behavior is important information, but only to the extent that it sheds light on how organismic contraints interact with environmental ones as a child tries to solve a particular problem.

2.2. Development and learning

Returning to our discussion of development and learning, we propose that the term "development" be reserved for those changes associated with solving "developmental tasks," those tasks which all children must solve in order to survive. The term "learning" could then be used to describe changes associated with "non-developmental tasks," those tasks that a child does not need to solve in order to survive. But how exactly should one decide whether a task should be characterized as a developmental or non-developmental one? Most developmentalists would agree that behaviors involved in eating, and avoiding danger have clear survival value. More specifically, behaviors such as chewing, grasping, crawling and walking would seem to be clear examples of solutions to the developmental tasks of eating and avoiding dangerous situations. Likewise, behaviors such as riding a unicycle or finger tapping have less clear generality and should be characterized as non-developmental tasks. In many ways our distinction of development and learning parallels the traditional dichotomy in the field of motor development of phylogenetic and ontogenetic change (Newell, 1986; Roberton, 1984). Traditionally, phylogenetic change was viewed as change occurring in all members of the species and so would be associated with what we describe as developmental change. In contrast, ontogenetic change was viewed as those changes idiosyncratic to the individual and so would be associated with what we describe as learning. We reject the phylogenetic/ontogenetic distinction on two counts. First, these terms have traditionally been associated with a maturational account motor development. This account carries a lot of theoretical baggage and is not an effective account of changes that occur over the life span. Second, the traditional phylogenetic/ontogenetic distinction places phylogenetic (developmental) change at the species level of the hierarchy depicted in Fig. 1 and ontogenetic change at the top two levels. We suggest that development and learning occur throughout the top three levels of the hierarchy depicted in Fig. 1 and that these should be distinguished from evolutionary change that occurs at the species level (the bottom of Fig. 1).

An additional criterium for determining whether the acquisition of a particular behavior should be attributed to development or learning is whether the behavior exhibits clear levels of expertise. For those behaviors that emerge due to development, we should expect relative (but not complete!) uniformity in expression and less clear levels of expertise as a result of very similar organismic, environmental, and task constraints over the course of evolution. Although there is clearly some variation in how people walk and sit, it is difficult to conceptualize truly "expert" levels of walking or sitting. Due to evolutionary pressures sitting and walking are practiced constantly throughout life and all relatively healthy individuals achieve the same overall level of function.

Even though one can think of certain individuals as achieving a level of expertise in walking, as in the case of tight-rope walkers, this expert level of behavior appears to result from "learning" added onto the basics acquired through development. Thus, if there are clear levels of expertise observed in a particular behavior, we suggest that "learning" rather than "development" accounts for the advances beyond the behavioral norm. Other forms of motor behavior, such as juggling and even drawing, show clear expert levels of performance, and in our view can be clearly viewed as the result of learning rather than development.

2.3. Adaptive value of variation

Another central assumption of our approach is that variability is inherent to biological systems and that in living, acting, biological organisms this variability serves an adaptive function. On any given task, or analysis of a particular behavior, variability, rather than stability is the norm. That is, if one looks closely at any behavior, performance is highly variable. It is highly variable between children of the same age, in a child over successive observations, and even in a child within the same period of observation (Siegler, 1996, 2000). At present, no developmental theory adequately captures the importance of this variability, although a growing number of developmental researchers are beginning to embrace aspects of variability in their work (Arterberry & Bornstein, 2002; Bornstein, 2002; De Weerth & Van Geert, 2002; Gilmore & Thomas, 2002; Hadders-Algra, 2002; Oakes & Plumert, 2002; Piek, 2002; Rosengren, 2002; Siegler, 1996, 2000, 2002; Snyder, Webb, & Nelson, 2002; Thelen & Smith, 1994; Van Geert & Van Dijk, 2002; Yonas, Elieff, & Arterberry, 2002). We argue that the failure to examine issues of variability may be attributed to a number of factors, including entrenched underlying theoretical assumptions (including ones about age-related changes), equating variability with noise (either in the data or due to the measurement instruments), and the research methodology (both design and statistics) used to evaluate children and how they acquire behaviors over the course of their lives (Rosengren & Braswell, 2001). Past theories of development, in our view fail, because they have failed to acknowledge and account for these different types of variability.

Variability stems, in our view, from basic evolutionary pressures that enable both the individual organism and the species overall to adapt to their local environment in order to survive. In early life this adaptation process increases the likelihood of survival. In later life, this variability is less necessary for survival, but instead enables greater flexibility in behavior, and greater efficiency in acquiring new skills and behaviors.

2.4. Constraints

Constraints enable behavioral change to occur. Constraints, both within the organism, and within the context of the organism–environment fit serve to both limit and enable the emergence of particular behaviors at any given period of time in the life span. Constraints operate at three levels: task, organism, and environmental (Newell, 1986). Without these constraints, the developing organism would be faced with an overwhelming amount of information. For the very young infant the constraints enable the infant to pick up information that is relevant for survival. In a sense, these initial constraints involve a “pre-selection” of information (this pre-selection is due to evolutionary pressures). For example, imagine if all the perceptual systems of the infant were equally developed at birth. This would mean that the infant is virtually bombarded with information from the visual system, auditory system, olfactory system, etc. However, the perceptual systems mature at different rates. For example, the visual system, which is arguable the most sensitive and picks-up the most information, is relatively immature at birth (Geary & Bjorkland, p. 59). We argue, that this serves to constrain the information that the infant can attend too initially. If this system, were fully functionally at birth, the richness of information that an infant picks up could very well overwhelm the system so that the infant would never learn to attend to other sources of information, such as the auditory or tactile ones. Thus, the differential time course of development of the perceptual systems may serve as a constraint that promotes the most adaptive development. In other species where auditory information may be less important (i.e., because only a few danger signals need to be picked up and language is not available), the visual system may mature at an earlier rate.

Thus, in our view we need a highly constrained system in order for the infant to develop in an optimal manner. Without these constraints, the infant would be overwhelmed with both information and choices and the probability of survival would be greatly diminished. Imagine, if all cells in a system or network were equally stimulated—then no selection would occur—or the selection that did occur might be random in nature—putting the organism at risk.

2.5. Selection

Selection pressures work at a number of different levels of the organism–environment system. While evolutionary theory has focused primarily at the level of the species and individual, we view selection pressures as also operating on the level of individual behaviors. In this way variation and selection occur at all levels of the system depicted in Fig. 1.

With advances in health and medicine in the industrialized world, selection pressures have declined, enabling a wider range of performance levels to emerge and survive. We view this phenomenon as a loosening of the environmental constraints. What this implies is that the possible range of behaviors adequate for performing a developmental task has been expanded. Selection pressures, are still present, but function in a more limited manner at the individual level. Selection pressures at the level of individual behaviors are more strongly influenced by the match between the organismic and environmental constraints. In the absence of a specific task, selection pressures are substantially reduced—and a large number of behaviors will be evident. For example, when a young infant is lying on her back, there is no explicit task for her (she may obviously take on the task of learning how her limbs work with respect to gravity), in this situation her arm and leg movements may show a high level of randomness. Yet, even in this situation, periods of cyclical behavior may emerge as a function of organismic constraints, as in the patterns of kicking and arm movements observed by Thelen and coworkers (Thelen & Smith, 1994).

While the reduction of selection pressures at the individual level may have enabled a wider range of behaviors to emerge and survive, and a wider range of a particular behavior across individuals to emerge and survive, this is not without consequences. For example, consider the onset of walking. This behavior has been described as having a very wide range of onset, anywhere from 8 to 17 months of age. We suggest that this wide range of onset is partially a consequence of better health and nutrition reducing the selection pressures on individuals who are at either extreme of the distribution. Fig. 2 shows a normal distribution of potential walking onsets. Selection pressures operate at both tails of the distribution. That is, the probability of survival for infants who fail to walk or walk too soon is less than for those infants who fall towards the center of the distribution. Infants with a late onset of walking may have greater difficulties moving out of harms way or obtaining food or warmth. Likewise, infants who walk very soon may lack the cognitive abilities to avoid dangerous situations. A nice example of this is provided by Adolph (1997) who found a relationship between walking experience and avoiding dangerous situations (specifically avoidance of walking down a slope that is too steep). With increased walking experience infants were better at differentiating between the risky and safe surfaces. This is one reason why placing infants in walkers is hazardous. The greater locomotor ability of the infant in the walker may exceed their capacity to determine where it is safe or not safe to locomote. Accident statistics reporting numerous injuries per year to children under the age of 15 months placed in walkers support this explanation (American Academy of Pediatrics, 2001).

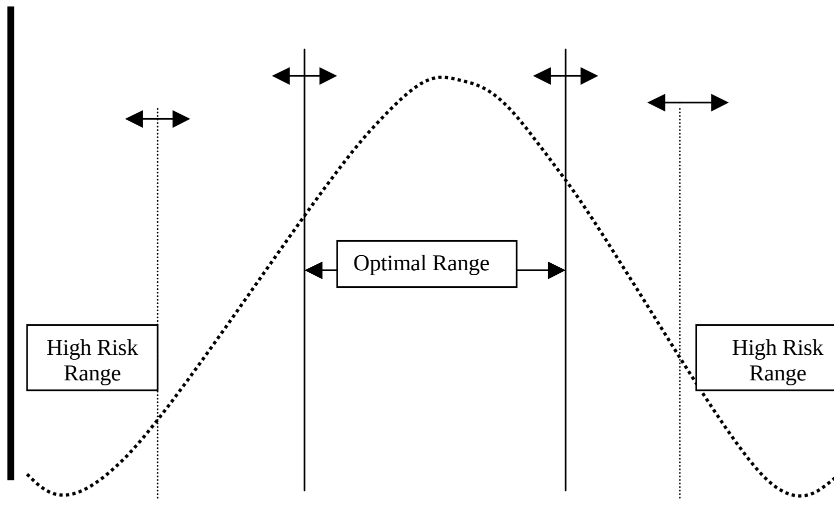

Fig. 2. The effects of environmental constraints on behavior. Curve represents distribution of a behavioral property (i.e., on the onset of walking), arrows indicate shifts in optimal and high risk range as a function of changing environmental constraints.

2.6. *Freezing, freeing, and exploiting degrees of freedom in development and learning*

Bernstein (1967) is credited with articulating an essential problem in the study of human motor behavior, namely how do humans solve the problem of redundant degrees of freedom. Bernstein (1967) noticed that the many possible (non-linear) interactions between different components of the human body (e.g., joints, muscles, tendons, etc.) make separate regulation of these components very unlikely. Specifically, any behavior, such as grasping an apple from a tree, can be performed in an infinite number of ways. The degree of freedom problem raises the question of how children and adults select among an infinite set of possibilities, the one behavior to perform in a particular context.

One manner in which the complexity of the problem, or degrees of freedom, can be reduced is by the formation of functional muscle synergies or coordinative structures (Turvey, 1990). For instance, the action pattern that emerges when children attempt to grasp an object (task constraint) can be understood by the relation between organismic and environmental constraints. The sources of organization of these coordinative structures can be found in Newell's (1986) 'constraints on action.' For example, Van der Kamp et al. (1998) showed that the ratio between object size (an environmental constraint) and hand size (an organismic constraint) determined when children shifted from a one-handed to a two-handed grasping pattern. Thus, information about the object size guides the grasping pattern and in this sense acts as a constraint that determines the particular coordination pattern that will emerge.

In a more recent experiment, Van Hof et al. (2002) examined how the development of crossing the midline is interwoven with the development of bimanual reaching. Previously, it was held that the development of midline crossing is uniquely determined by maturation of the hemispheric specialization (Provine & Westerman, 1979) or the maturation of spinal tracts (Morange & Bloch, 1996). Van Hof et al. observed infants longitudinally at 12, 18 and 26 weeks of age while reaching for two balls (3 and 8 cm in diameter) at three positions (ipsilateral, midline, and contralateral). With age, the infants increasingly adapted the number of hands used to the size of the object. The number of reaches crossing the body midline increased with age. Furthermore, the majority of the midline crossings were part of two-handed reaches for the large ball and occurred at or after onset of bimanual reaching. Together, this strongly suggests that the development of crossing the body midline emerges in the context of bimanual reaching. It is concluded that the need to grasp a large ball positioned contralaterally with two hands induces midline crossing. Hence, the development of midline crossings is not exclusively dependent on organismic constraints (e.g., the maturation of hemispheric connections), but on their interaction with environmental constraints (e.g., object size).

Interestingly, researchers have often discussed the solution to the degrees of freedom problem in terms "learning." Specifically, a number of researchers have described three stages of "learning" with respect to Bernstein's conception of degrees of freedom; an initial freezing of degrees of freedom as the individual is beginning to acquire a new skill, a freeing up of the degrees of freedom as greater skill is acquired, and an eventual exploiting of degrees of freedom as expertise is acquired. Researchers (McDonald, van Emmerik, & Newell, 1989; Vereijken, Whiting, & Beek, 1992) have also provided empirical evidence for three stages in "learning" with respect to Bernstein's degrees of freedom. For instance, when a subject "learns" to ski on a ski-simulator (a platform attached to a spring that enables the platform to move side to side in a ski-like fashion) Vereijken et al. (1992) found that at the beginning of practice, novices tried to "freeze the system" by applying force to the platform at a biomechanically inefficient moment. When using this strategy, one does not benefit from available elastic forces stored in the stretched springs of the device. With experience, subjects "learned" to "free up the degrees of freedom" and eventually "exploit" the characteristics of the apparatus, postponing their force production until after the platform had passed the center of the apparatus and had begun to slow down. With this strategy, subjects could make use of the elastic forces that gave them a 'free ride' back to the center of the apparatus and beyond, allowing them to reduce their active muscle forces. In our view, this is clearly a non-developmental task, because learning not to ski does not place one at greater risk for survival.

Development might also be described in terms of freezing, freeing, and exploiting degrees of freedom. For example, Ledebt (2000) found changes in arm posture and movement of the arms in relation to the step width of children who were just beginning to walk. During the first 10 weeks of independent walking the arms were held in an upright fixed posture (freezing of degrees of freedom). As the children's step width and balance control improved there was a corresponding increase in arm movement (freeing of degrees of freedom). Presumably, these arm postures aid to stabilize the body in an upright posture and according to Ledebt (2000) enable the beginning walkers to more efficiently propel themselves forward (exploiting degrees in freedom). In our view, this process of freezing, freeing, and exploiting occurs throughout development.

There are a number of different levels at which freezing, freeing, and exploiting occurs in the developing organism (see Fig. 3). At one level, organismic constraints may serve to initially freeze the system when the organism is at a particular behavioral level. These constraints function so as not to overwhelm the child and to enhance the probability that the child will

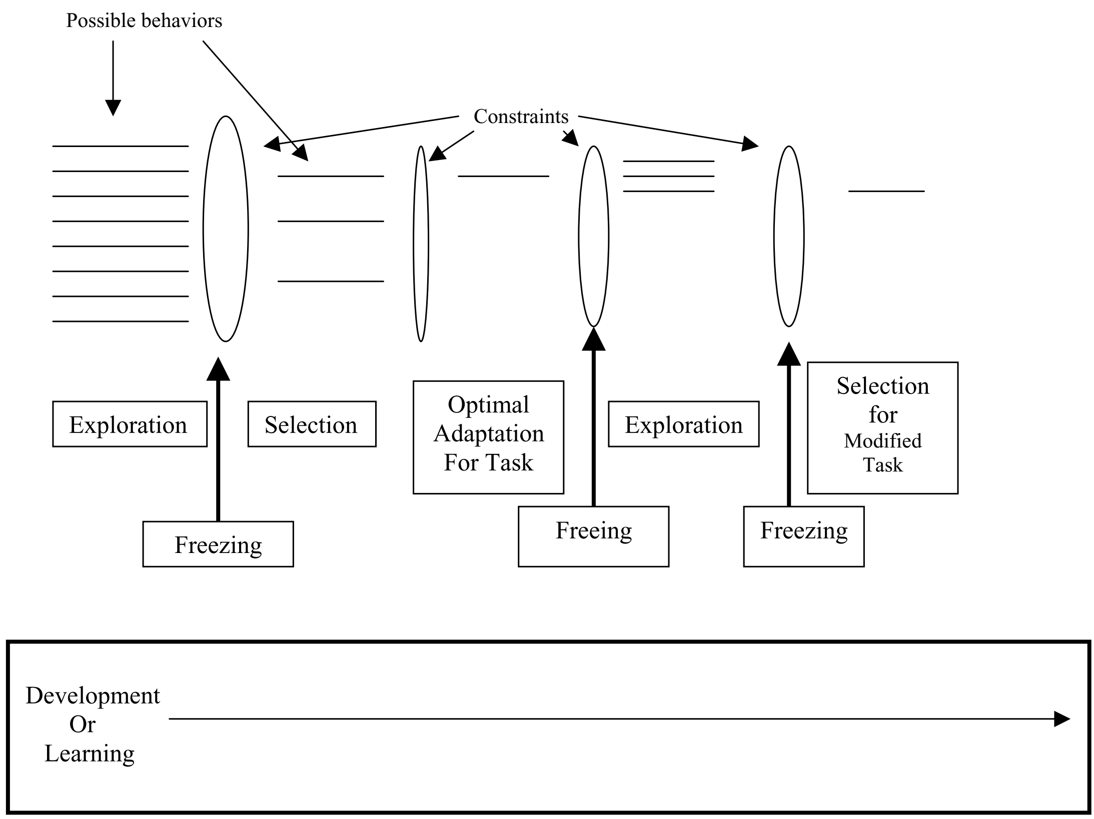

Fig. 3. A proposed model of Development and Learning.

acquire the necessary information to perform a particular task. Over time (with both experience and maturation) some of these constraints may loosen—providing a freeing of degrees of freedom. Then at later stages the organism is likely to acquire the ability to exploit the degrees of freedom in order to effectively explore and adapt to the environment. It is likely that organismic constraints that serve to freeze the degrees of freedom at this level have evolved to aid the organism to develop in particular environments. However, while the constraints might be viewed as primarily within the organism, they have evolved in response to environmental pressures, and so should be viewed not as purely maturation (residing solely within the organism) but should be viewed as capturing the organism–environment fit over evolutionary time. The example, provided previously of the infants early perceptual abilities provides another case where it appears as if organismic constraints, in this case an immature visual system, "freezes" the system and enables the child to focus attention on relevant information in the environment. At this level, the organismic constraints function in a general overall fashion. These constraints serve to channel behavior in particular directions.

At a different level, we see these processes (freezing, freeing, exploiting) as occurring within an organism's performance on any given task—whether these be the evolutionary functional tasks described above or whether they are some more arbitrary laboratory task. In this sense, similar processes are viewed as operating in both learning and development. What separate these two phenomena is the task that is being confronted and how the various constraints interact to lead the emergence of particular behaviors. We suggest that in the environment where the organism has evolved, due to selection pressures, a relatively small number of optimal solutions will have emerged for developmental tasks over the course of evolution. For non-developmental tasks, depending on the task demands and how well they interact with organismic constraints, few or many optimal solutions will emerge. Take as an example learning to ride to a uni-cycle. This is a very difficult task, requiring excellent balance and coordination, and clearly not one we have evolved to solve. A particular limited number of ways of solving this task emerge. Note also that when an individual is learning this task they freeze certain parts of their body (such as the arms in an extended position). As skill is acquired, the arms are freed up to perform other tasks, such as juggling. For other tasks, such as writing with an implement, a wider range of optimal solutions emerge. Specifically, a wide range of grip configurations involving different configurations of the fingers and thumb can be found in the general population, yet this variation does not appear to interfere with successful writing.

2.7. Concluding comments

Horowitz (2000) has discussed what she refers to as a "peculiar tendency" of developmental science to devalue data collected within a different theoretical tradition. In her view, new theoretical accounts should be judged on how well they can accommodate existing data. This ignores the fact that research methodology is always imbedded in particular theoretical traditions. Thus, a new theoretical perspective may at minimum require a reanalysis of existing data, but it is not unreasonable to think that new data must be collected as well. Just as new technology (such as a new form of telescope) may enable the collection of new kinds of data, a different theoretical perspective may lead to a different vision about what types of data are important. With respect to the TASC-based approach, this approach can be used to examine existing datasets to the extent that information about variability is collected and the data were collected as the child was performing a clearly defined task. To the extent that only mean data has been collected (or reported) and the task is ill-defined then this data is not of much use.

We suggest it is time for a renewed focus on the functions of behavior, only this type of approach will enable us to determine whether we should make a distinction between "learning" and "development" or whether it is time for these concepts to be replaced entirely by the notions of freezing, freeing, and exploiting the degrees of freedom of the system. By examining whether the same processes can be applied to describe the emergence and change of behaviors that are and not privileged we can begin to address this issue. But in order to address this question we will need to collect new data, data that enables us to examine how variability in a behavior changes over time and experience as a function of changing patterns of interacting constraints.

Notes

1. Throughout this paper, we will use the term "motor development" to refer to the academic discipline that focuses on the investigation of the acquisition of motor skills in infancy and childhood. We do this because this is the "domain" label that is nearly always asso-

ciated with research in this discipline. At the same time we acknowledge that this label assumes a particular theoretical perspective and its concomitant view of "development" and "learning."

2. We have added the emphasis. We certainly advocate that children with severe or even moderate motor difficulties should be provided with help to improve their motor behavior. However, the nature of this help and the "label" given to the child will vary greatly as a function of whether the child is viewed as "normal" but "delayed" vs. "having a disorder."

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